The uncertainty in sound insulation of an industrially prefabricated lightweight timber construction

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ABSTRACT

The variations in sound insulation are often large for lightweight constructions. A large number of measurements is therefore necessary to reliably evaluate the acoustical properties of a lightweight construction. The Swedish company Lindbäcks Bygg has since the '90s developed a timber system based on industrially prefabricated volumes. This paper presents a statistical evaluation of all measurements of impact and airborne sound insulation made on the system between 2011 and 2014. The objective was to quantify the variations in impact and airborne sound insulation in both weighted terms and 1/3 octave bands, and investigate the relationship between workmanship and acoustical properties. The study consists of a large number of vertical measurements between nominally identical room pairs. The measurements were grouped according to date, room size, floor level and assembly team. The variations were larger for impact than for airborne sound insulation. The impact sound level was higher in large rooms, which may have been caused by the method of joining several volumes. The sound insulation was somewhat better on higher floors. No significant differences could be identified between the different assembly teams. To improve the system, the impact sound insulation should be in focus.

Keywords: Airborne sound, Impact sound, Uncertainty, Lightweight constructions
I-INCE Classification of Subjects Number(s): 51.3 51.5

1. INTRODUCTION

When performing building acoustic measurements in the field, the uncertainty of measurements should always be considered. The legal requirements are given as fixed values but the uncertainty of field measurements related to the operator and measurements procedure is typically 1 dB (1). Variations are also caused by several other parameters such as room size, geometry, floor layout, construction and workmanship. A study by Craik et al. on a precast concrete construction determined the standard deviation due to workmanship to be 2 dB per 1/3 octave band for both airborne and structure borne sound transmission (2, 3). In a similar study by by Trevathan and Pearse (4), the standard deviation in airborne sound reduction of a lightweight system due to workmanship was calculated to 1,1 dB in a 1/3 octave band. Both studies were made on nominally identical constructions. A study by Johansson (5) on 170 apartments of a lightweight construction determined the standard deviation in 1/3 octave bands between nominally identical units to be 0,8-3,7 dB regarding impact sound level. The uncertainties in sound insulation measurements related to both workmanship and measurement procedure means that a large number of measurements is necessary to reliably evaluate the acoustical properties of a construction system.

1.1 Volume Based Building

The Swedish company Lindbäcks Bygg has since the '90s developed a timber system based on industrially prefabricated volumes. The volumes are industrially produced in a factory in a controlled environment. The modules can be produced as single room apartments or as entities in a larger apartment. The modules are stacked at the building site so that the floor, ceiling and walls of adjacent modules are decoupled. At the junction connection, the modules are separated by elastomers, as illustrated in Figure 1. The constructional work in the field, when the buildings are erected, may have a larger influence on the sound insulation since the buildings are erected by different assembly teams.

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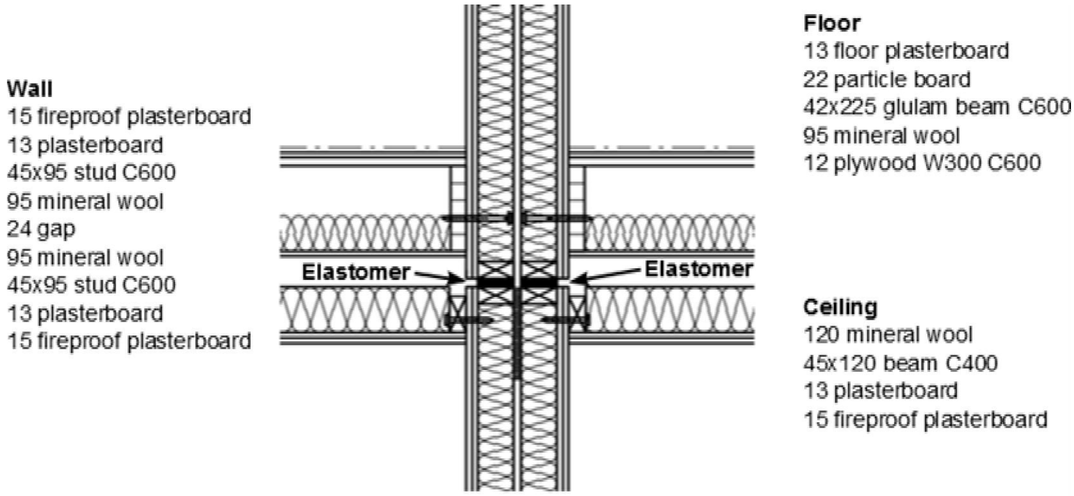

Figure 1 – Section of the junction connection of the volume based building system

Previous studies by Öqvist et. al. (6) and Ljunggren et. al. (7) have shown that a mismatch in the relationship between elastomer stiffness and static load can provoke deviations in sound insulation between floors. A significant constructional change was therefore implemented around 2008/2009 when the elastomer was changed to a product of higher quality.

Many acoustic measurements have been performed on the Volume Based building system throughout the years, primarily for auditing purposes before the tenants move in. Some significant constructional changes have been implemented throughout the years, but since 2008/2009 the system is equivalent. A previous study by Öqvist investigated 121 impact and 136 airborne measurements made between 2005 and 2012 (8). The measurements were grouped in subcategories of about 10-30 objects to isolate the different causes for variations. Since 2012, a large number of additional measurements have been made. The present study deals with measurements made between 2011 and 2014, thereby increasing the number of equivalent objects to about 60. Older measurements were omitted from the analysis, since the construction was significantly different.

1.2 Objective

The objective of this work is to quantify the variations in impact and airborne sound insulation for the volume based construction system, and to investigate the relationship between workmanship and acoustical properties.

2. METHOD

2.1 Building acoustic measurements

All measurements have been made according to SS-EN ISO 140-4 and SS-EN ISO 140-7 and the data has been evaluated according to SS-EN ISO 717-1 and SS-EN ISO 717-2 (9-12). The weighted sound insulation terms $L'_{n,w}$, $L'_{n,w} + C_{I,50\text{-}2500}$, R'_w and $R'_w + C_{50\text{-}3150}$ were calculated with 1/10 dB accuracy in order to get a more meaningful mathematical analysis of the results. The measurements were also evaluated in 1/3 octave bands.

2.2 Statistical analysis

The statistical analysis consists of 59 impact and 64 airborne sound insulation measurements in vertical direction. The measurements were all made between unfurnished rooms with the same floor layout. All measurements were made between 2011 and 2014 by Tyréns AB, with the majority made by the same operator. The measurements were categorised according to room size, floor level and assembly team. The different categories of measurements were studied with an analysis of variance (ANOVA) at 5 % significance level, using $L'_{n,w}$, $L'_{n,w} + C_{I,50\text{-}2500}$, R'_w and $R'_w + C_{50\text{-}3150}$ as response variables. Tukey´s test were used to determine significant differences in means. The results were calculated as Tukey 95% simultaneous confidence intervals.

2.3 Room size

The measurements were divided in two groups, large and small rooms. The large rooms represented living rooms with an average volume of 60-109 m^3. The small rooms represented bedrooms ranging between 16 and 42 m^3. The small bedrooms were rectangular in shape and the large living rooms typically had an unsymmetrical layout, which should imply a more diffuse sound field. Another key difference was that the bedrooms consisted of a single volume whereas the living rooms consisted of two joined volumes. For impact sound, 30 large and 29 small rooms were compared. For airborne sound, 32 large and 32 small rooms were compared.

2.4 Floor level

It was assumed that the separating construction in a two-storey building will experience the same static load as the top floor in a four-storey building. The top floor was thus designated as level 1, with increasing numbers towards lower floor levels as seen in Figure 2. The influence of static load on vertical sound insulation was evaluated by an ANOVA. The number of measurements on each floor level is given in Table 1.

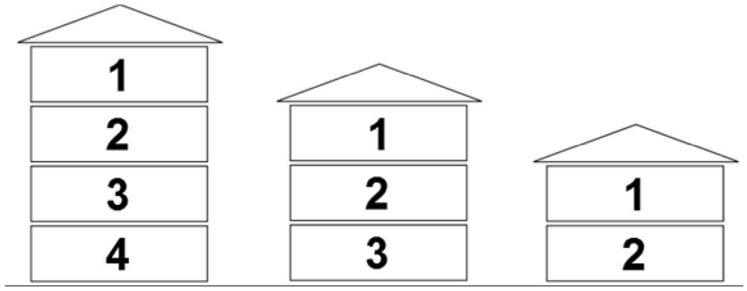

Figure 2 – Designation of floor numbers

Table 1 – Number of sound insulation measurements on each floor level

Floor level	Impact sound	Airborne sound
1	30	36
2	18	18
3	10	10

2.5 Workmanship

The measurements were grouped according to the assembly team that erected the building in the field. The assembly teams were designated with numbers 1 to 6. The influence of workmanship was presented in scatter plots, and evaluated by an ANOVA.

3. RESULTS

3.1 Results vs Time

All measurements of impact and airborne sound insulation are plotted against time in Figure 3 and Figure 4. The weighted sound insulation as well as the variation in sound insulation are more or less constant, except for a couple of outliers.

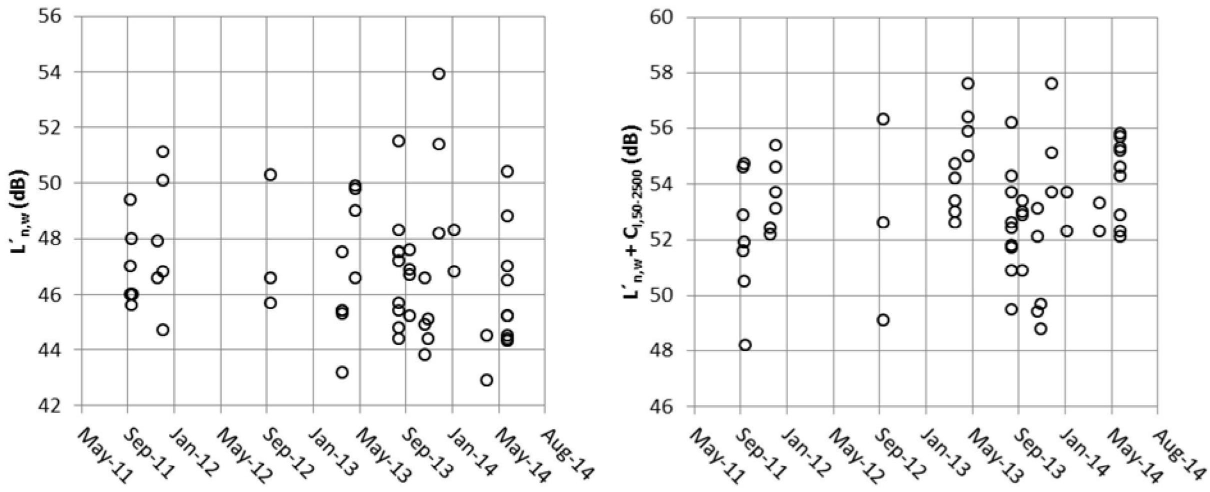

Figure 3 – Scatter plot of all impact sound insulation measurements

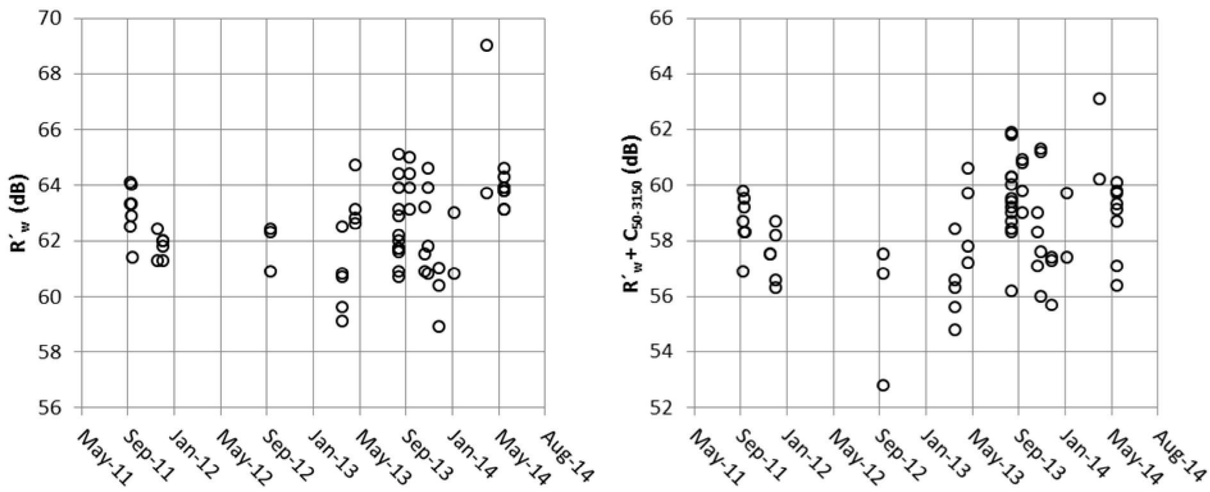

Figure 4 – Scatter plot of all airborne sound insulation measurements

3.2 Impact and Airborne Sound Insulation

The average sound insulation and corresponding standard deviation are given in Table 2 and Figure 5 and Figure 6.

Table 2 – Average sound insulation with the corresponding standard deviation within brackets

Group	$L'_{n,w}$ (dB)	$L'_{n,w} + C_{I,50-2500}$ (dB)	R'_w (dB)	$R'_w + C_{50-3150}$ (dB)
All measurements	46,9 [2,3]	53,2 [2,1]	62,6 [1,7]	58,5 [1,9]
Large rooms	47,6 [2,6]	52,7 [2,1]	62,4 [1,5]	58,5 [1,5]
Small rooms	46,1 [1,6]	53,7 [2,1]	62,8 [1,9]	58,6 [2,2]
Floor 1 (top)	46,6 [2,0]	53,0 [2,1]	63,0 [1,7]	58,9 [2,1]
Floor 2	47,0 [1,6]	52,9 [2,1]	62,9 [1,2]	58,6 [1,1]
Floor 3	47,5 [3,7]	54,2 [2,1]	60,8 [1,1]	56,9 [1,3]

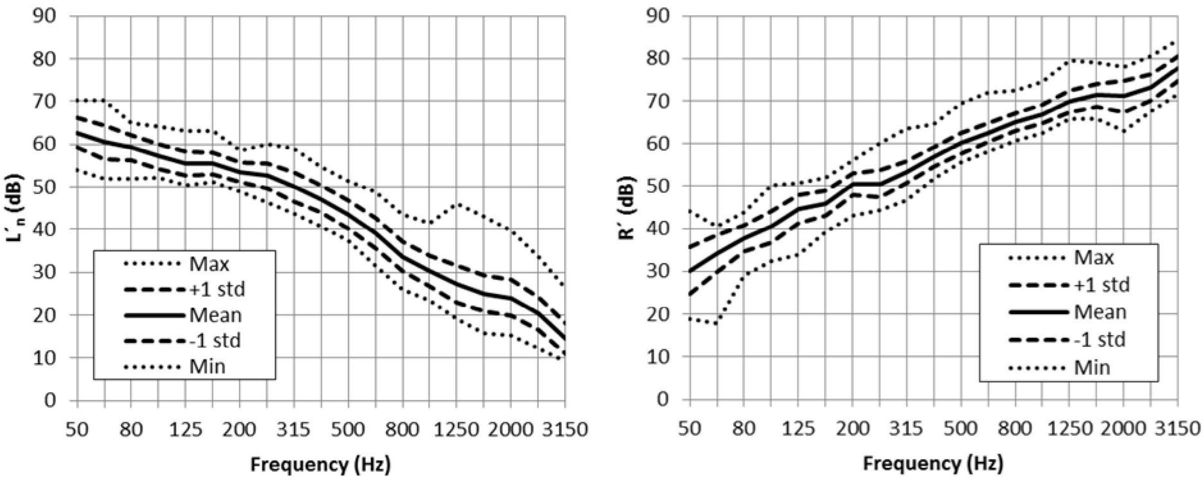

Figure 5 – Impact and airborne sound insulation in 1/3 octave bands for all measurements

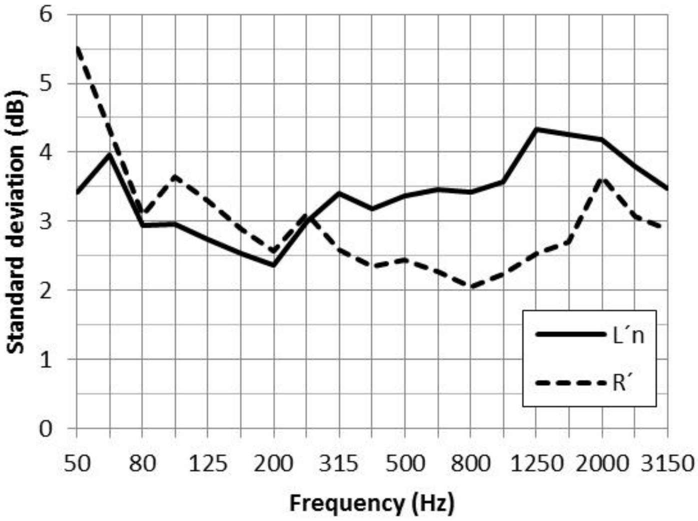

Figure 6 – Standard deviation of impact and airborne sound insulation for all measurements

3.3 Room size

The mean impact and airborne sound insulation in different sized rooms are given in Figure 7.

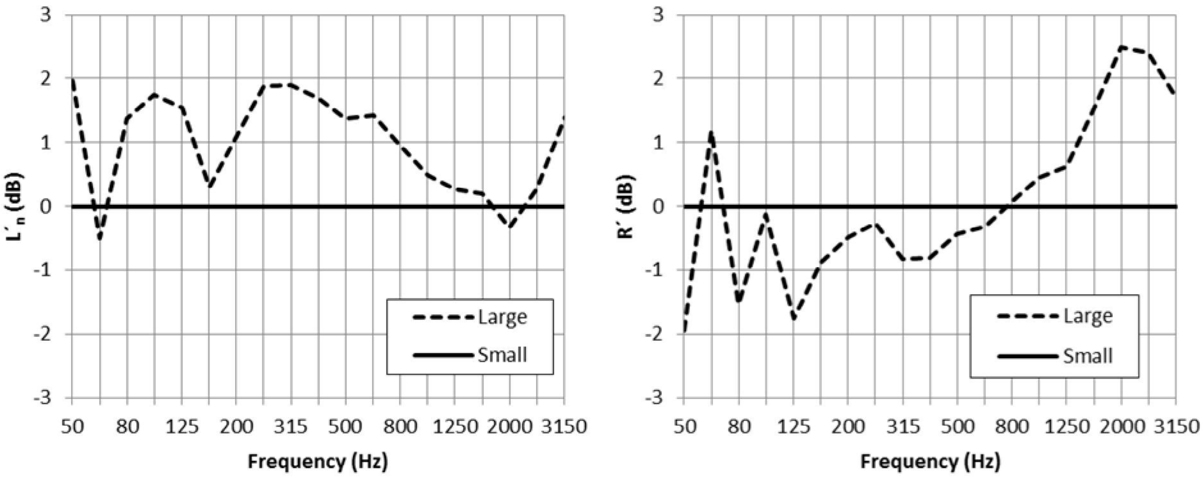

Figure 7 – Relative difference in impact and airborne sound insulation between large and small rooms

3.4 Floor level

The mean impact and airborne sound insulation on different floors are given in Figure 8. The sound insulation is slightly better on the top floor.

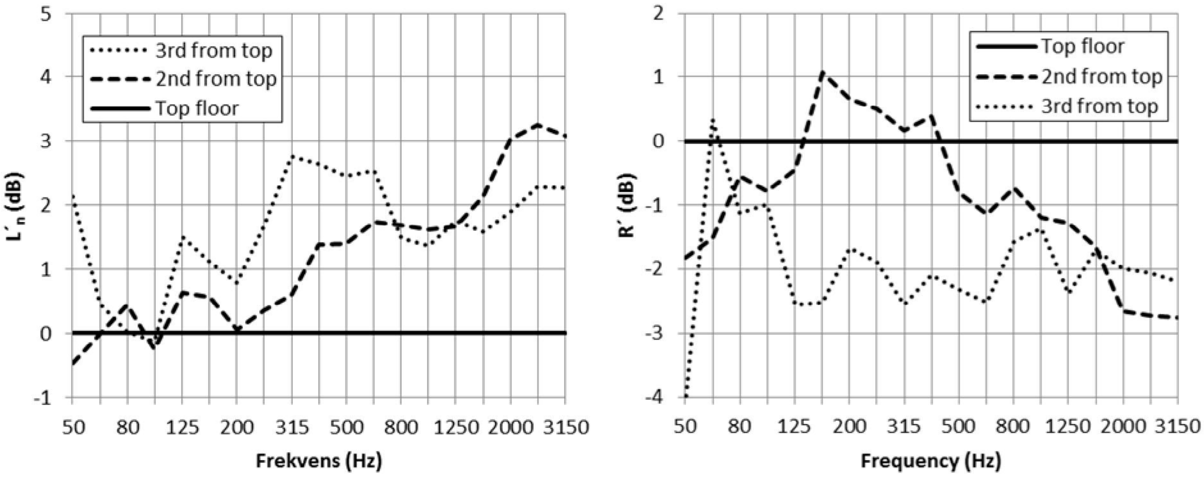

Figure 8 – Relative difference in impact and airborne sound insulation on different floors

3.5 Workmanship

The weighted impact and airborne sound insulation corresponding to each assembly team is given in Figure 9 and Figure 10.

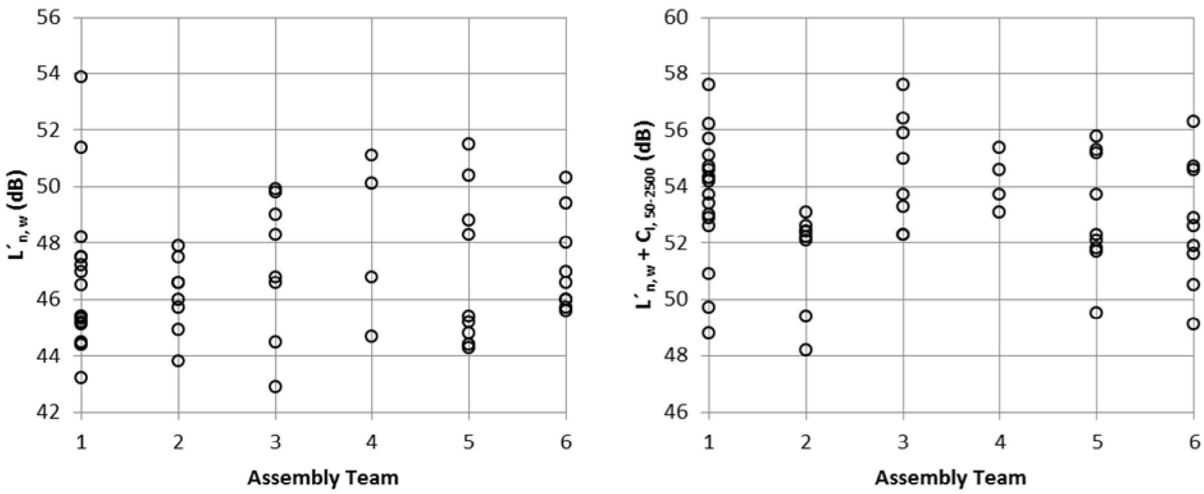

Figure 9 – Impact sound insulation for different assembly teams

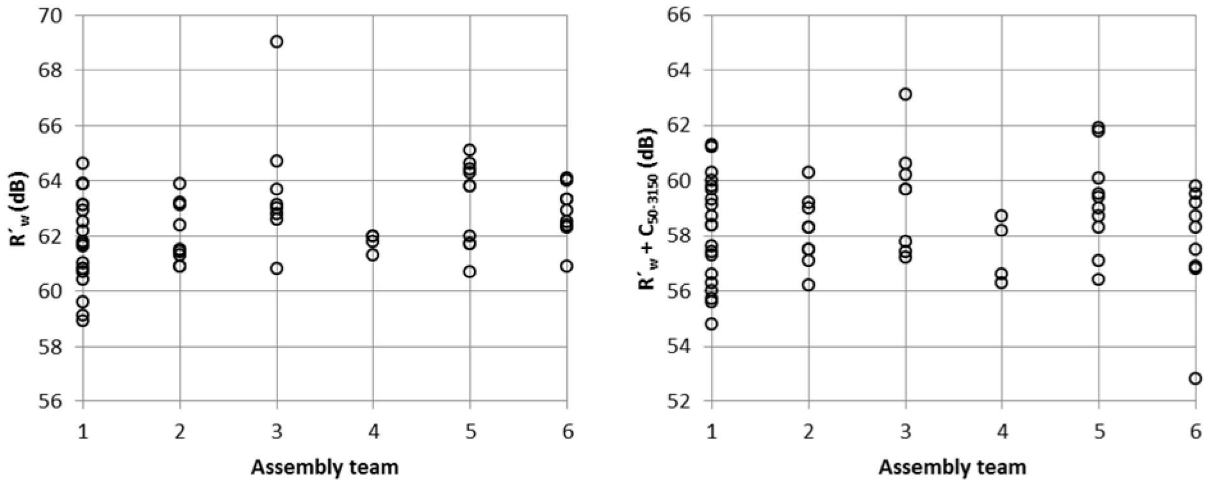

Figure 10 – Airborne sound insulation for different assembly teams

3.6 ANOVA

The results from the ANOVA study of the different categories are given in Table 3. The impact sound level was lower in the smaller rooms. No significant difference could be identified for the airborne sound insulation.

The airborne sound reduction was lower on floor number 3 (the bottom floor). No significant differences were found regarding impact sound insulation.

Table 3 – Tukey 95 % confidence intervals of difference in means

Parameter	$L'_{n,w}$ (dB)	$L'_{n,w} + C_{I,50\text{-}2500}$ (dB)	R'_w (dB)	$R'_w + C_{50\text{-}3150}$ (dB)
Room size – Small subtracted from large	Significant [0.3, 2.6]	Not significant [-0.1, 1.1]	Not significant [-1.3, 0.5]	Not significant [-1.1, 0.9]
Floor level – 1 subtracted from 2	Not significant [-1.5, 2.2]	Not significant [-1.8, 1.7]	Not significant [-1.2, 1.0]	Not significant [-1.6, 0.9]
Floor level – 1 subtracted from 3	Not significant [-1.0, 3.5]	Not significant [-1.0, 3.2]	Significant [-3.5, -0.8]	Significant [-3.6, -0.4]
Floor level – 2 subtracted from 3	Not significant [-1.5, 3.3]	Not significant [-1.1, 3.4]	Significant [-3.5, -0.6]	Not significant [-3.4, 0.1]
Workmanship – Comparison of 6 assembly teams*	Not significant -	Not significant -	Not significant -	Not significant -

*No significant difference in means could be identified between the six teams.

4. CONCLUSIONS

When all measurements were plotted against time, some outliers could be identified. One of the outliers (airborne sound insulation September 2012) could be attributed to problems with the measurement of reverberation time at low frequencies. If the outliers are disregarded, no clear trends can be identified over time. Overall, the variations in sound insulation are clearly larger for impact sound than for airborne sound. Lightweight constructions such as the volume system typically achieve good airborne sound insulation. The most common problem for lightweight constructions is impact sound, especially at low frequencies (13). To improve the volume system, the focus should be to improve impact sound insulation especially at low frequencies.

It is suggested that the difference in impact sound insulation between large and small rooms are partly caused by the joining of adjacent volumes. There are some structural connections at the joining edge which leads to a local reduction in impact sound insulation close to the joint. This discrepancy may be removed by improving the construction with a resilient connection. It may also reduce the variations in impact sound insulation.

The airborne sound reduction is somewhat lower on the lowest floor level. The results should only be treated as an indication though, since the number of measurements differs on the floor levels. Measurements are typically made during the construction phase, which means that the background noise often is higher on the lower floors (e.g. from workers and heavy machines). The degree of completion may also be higher on the top floor. Therefore, there are more top floor measurements.

No significant differences could be identified between the different assembly teams. There are several parameters such as differences between floor levels, building layout, room size etc. that affect the result. A fair comparison would only include nominally identical objects erected by different assembly teams. A very large number of well-documented measurements is therefore needed to perform a thorough study of the influence of workmanship.

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